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ARMY MEDICAL RESEARCH LABORATORY

FORT KNOX, KENTUCKY

ARMORED MEDICAL RESEARCH LABORATORY

Project No. T-2 - Final Report On Project T-2, Test of Heat Load Imposed by Protective Clothing, Subject: Ventilation Requirements of a Ventilated Suit.

21 September 1945

RESEARCH AND DEVELOPMENT DIVISION
OFFICE OF THE SURGEON GENERAL
DEPARTMENT OF THE ARMY

ARMORED MEDICAL RESEARCH LABORATORY
Fort Knox, Kentucky

Project No. T-2
File SPMEA 727-2

21 September 1945

1. PROJECT: NO. T-2 - Final Report on Project T-2, Test of Heat Load Imposed by Protective Clothing, Subject: Ventilation Requirements of a Ventilated Suit.

a. Authority: Letter, 1st Endorsement, Office of the Surgeon General, Washington, D.C., dated 1 December 1944.

b. Purpose: To determine the ventilation requirements of an impervious ventilated suit for use in hot working environments.

2. DISCUSSION:

A positive pressure impervious ventilated suit for industrial purposes was submitted by Chemical Warfare Service for study by this laboratory. This suit, made of nylon fabric impregnated with neoprene, was ventilated by positive distribution of air. The study was undertaken to determine the volume, the temperature, and the water content of the ventilating air that would permit men to work in the suit with comfort in environments with dry bulb temperatures up to 120°F.

3. CONCLUSIONS:

a. To maintain comfort for men working in environments with dry bulb temperatures up to 120°F. and air movement up to 70 fpm. the following suit ventilation characteristics were satisfactory:

(1) Air flows from 1.5 to 2.5 lbs. per minute.

(2) Water content of the incoming air below 60 grains per pound of dry air.

(3) If the air flow is 2.0 - 2.5 lbs. per minute and the water content 45 grains or less, the temperature of the incoming air may vary between 60°F. and 130°F.

4. **RECOMMENDATIONS:**

a. That provision be made for a maximum air flow of approximately three (3) pounds per minute with lowest possible water content below 60 grains per pound of dry air.

b. That provision for individual adjustment of air flow for each suit be provided.

c. That for further improvement of the suit additional studies be conducted to determine the best internal distribution of the ventilating air.

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3 Incls.
#1 - Appendix
#2 - Photographs (2)
#3 - Figure (1)

APPENDIX

I. DESCRIPTION OF THE VENTILATED SUIT:

A ventilated suit for certain industrial uses was submitted by Chemical Warfare Service for study by this laboratory. The experiments were planned to determine the necessary ventilation characteristics. The suit offered for testing was not a final model. As such, it was to be studied also to secure data and information which would facilitate the construction of improved ventilated suits.

The suit (Photographs Nos 1 and 2) weighed 19 pounds and was made from neoprene impregnated nylon (0.5 mm thick). A heavy zipper ran transversely across the back to allow the men to enter and leave the suit. The ventilating air entered the suit in the back after passing through a seven-foot length of cloth covered rubber hose (1"ID). The air was distributed internally by a spider of smooth bore flexible rubber tubing to the most distal parts of the suit (Fig. 1). From the ends of the tubing, the air circulated over the body of the man to discharge through a single 1¼ inch opening in the back of the suit. Three other exit openings were available but were not used in this test because samples of the mixed outflow were desired.

II. METHOD:

The studies were made on eight acclimatized men who walked for two-hour periods on a treadmill in a hot room wind tunnel. A complete list of the variables controlled in each experiment is given in Table 1 together with the range of values employed, the method of measurement, and the time of recording data.

During each test period the man in the suit walked in the nude except for socks and low quarter shoes and a control subject walked behind him dressed in herringbone twill fatigues. Interruptions were made to allow the recording of data detailed in Table 2. Analysis of this detailed data indicated such large internal variations that generalized equations of thermal exchanges between man and environment could not be developed. Therefore, these demonstrated limitations of air calorimetry in impervious suits allowed only a qualitative evaluation to be made of ventilation requirements.

III. RESULTS AND DISCUSSION:

a. Ventilated Suit Design

Although the suit weighed 19 pounds, this was not considered excessive due to the lifting action of the ventilating air. A free air space of 1 to 5 inches was maintained between the suit wall and the surface of the man except for small constant areas of contact at the shoulders and inconstant points of contact at elbows, knees, and hands. The ballooning of the suit gave an appearance of greater clumsiness than was actually the case. The subject could walk without difficulty. The gloves were satisfactory for grasping but would not permit any delicate manual operations. Vision was considerably restricted particularly to the sides and downward. Fogging of the glass facepiece was no problem.

The dimensions of the suit were not adjustable and would not accommodate a man of more than 72 inches in height. The shortness of the shoulder to crotch length limited the use of the suit and caused chafing of the skin of the groin in most subjects. Entering and leaving the suit was difficult despite the long zipper opening across the back and skin contact with the exterior of the suit would easily occur at these times. Assistance was always required and tearing at the seams took place on several occasions. The air and water tight zipper was not sufficiently durable and was replaced with a Crown type zipper which was not air tight.

The neoprene impregnation rendered the basic nylon fabric nearly impervious to water at the pressure of 1 to 2 mm of mercury used in the suit. However, leakage of sweat was noted on occasion and seepage of water could be made to occur either by increasing the pressure or by rubbing the outer surface of the fabric.

Depending upon the volume of air inflow, the air pressure at the entrance to the spider ranged from 18 to 40 mm. of mercury. Because of the low outlet resistance internal suit pressures did not exceed 2 mm at the highest flow rates (35 cfm). There was a small change in the temperature of the air during its passage through the spider. However, a considerable temperature change occurred within a short distance of the outlets due to heat transfer from the body and the suit.

The design of this suit should not be considered optimal and several deficiencies have been indicated. Because of the excellent protective qualities of the ventilating air against excessive heat load it appears likely that a simplification of suit and spider construction and particularly a reduction in the overall size of the suit would render it less clumsy and better adapted for practical use. Such alterations would change the characteristics of the suit as presented here and possibly decrease the demand for cooling and dehumidifying the inflowing air. It is likely that the distributing system within the suit is unnecessarily complex and offers too high resistance, since approximately 40 mm of mercury are required at the inlet to attain an air flow of 2.5 lbs/min. The heat of compression of the air is a drawback under such circumstances.

b. <u>Ventilation Requirements</u>

In external environments ranging from 70°F. to 120°F., tolerable working conditions in the suit could be maintained over a wide range of inlet air temperatures. When the moisture content was kept at less than 45 grains per pound, a range of inlet air temperatures from 60°F. to 130°F. was acceptable. However, optimal comfort* was provided by the use of the lower inlet air

* Optimal comfort of the subject was associated with the following physiological conditions: sweat loss of less than 500 grams per hour and a rectal temperature of less than 100°F. at cessation of a two hour work period. (A work rate of 250 to 300 cal/hr.)

temperatures (70° to 80°). An increase in the ventilation rate improved the comfort of the subjects and resulted in a lowering of sweat loss and final rectal temperatures. Conditions leading to optimal comfort are desirable for maximal efficiency. Since they vary from individual to individual, it is suggested that provision be made enabling each man to regulate the volume of air flowing into his suit to meet his specific needs for comfort.

Precise psychrometric control of the ventilating air is not important. The three critical variables controlling heat loss-volume, temperature, and moisture content-can compensate for one another to a considerable extent. Standard air conditioning apparatus having the following characteristics will meet the requirements: capacity - up to 3 lbs. per minute per suit, and adjustable by the man; moisture content - down to 45 grains per pound of air; temperature of air delivered to the suit - down to 70°F. (precise control not required).

TABLE 1

Variables Controlled During Each Experimental Period

Variable	Range Employed	Method of Measurement	Time of Measurement
Wind Tunnel DBT	70°- 121°F.	Mercury stem thermometer	Every 15 mins
Wind Tunnel WBT	58°- 90°F.	Mercury stem thermometer Motor driven psychrometer	Every 15 mins
Tunnel Wind Velocity	70 ± 20 ft/min	Hot wire anemometer Velometer	Every 15 mins
Suit inlet DBT	59° - 134°F.	Mercury stem thermometer	Every 15 mins
Suit inlet moisture content	41 - 88 grs/lb	Air washer dewpoint	Automatic Constant Adjustment
Suit inlet airflow	1.1-2.8 lbs/min (15 - 35 cfm)	Sharp edged pipe orifice meter	Every 15 mins
Treadmill Speed (3.0% Grade)	2.3-2.4 mph	Stopwatch	Initial

Incl. #1

TABLE NO. 2

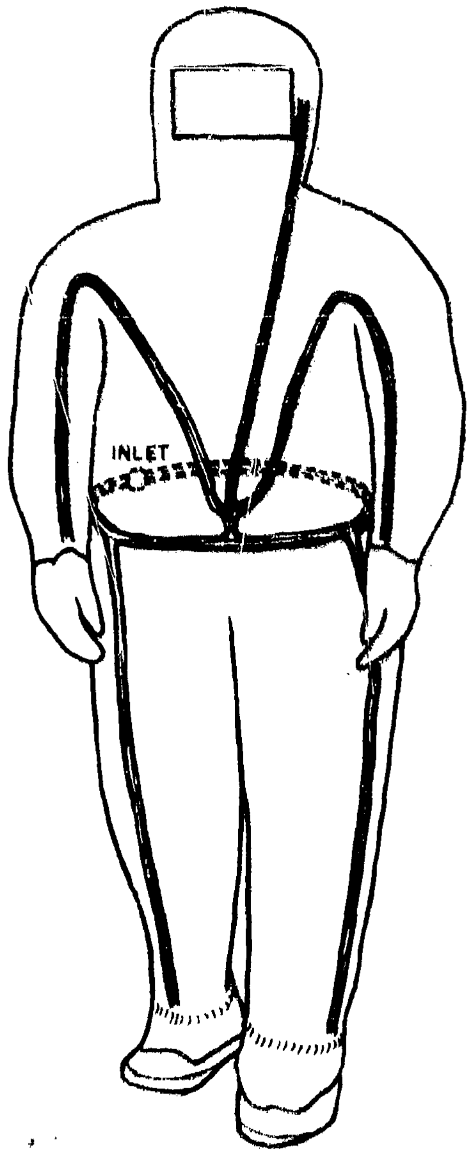
Variables Observed During Each Experimental Period

Variable	Method of Measurement	Time of Measurement
A. Subject in Suit:		
Rectal Temp. °F.	Clinical Thermometer	At start, 90 mins, & finish
Skin Temp. °F.	Copper-constantan Thermocouples (5)	Every 10 mins
Sweat Loss* - gms/hr	Beam balance	At start, 90 mins, & finish
Oxygen consumption (Cals/hr)	Tissot spirometer (12 min collection) and Haldane analysis	At 45 and 75 mins
B. Control Subject:		
Rectal Temp. °F.	As above	At start, 90 mins, & finish
Sweat Loss - gms/hr	As above	At start and finish
Oxygen consumption (Cals/hr)	As above	At 15 mins and 105 mins
C. Environmental:		
Suit wall Temp. °F.	Copper-constantan thermocouples (5)	Every 10 mins
Suit air Temp. °F.	Copper-constantan thermocouples (5)	Every 10 mins
Suit air pressure mm Hg	Mercury manometer	Every 15 mins
Suit outlet DBT °F.	Mercury stem thermometer	Every 15 mins
Suit outlet WBT °F.	Mercury stem W.B. thermometer	Every 15 mins
Tunnel wall radiation Temp. °F.	Radiometer	At start and finish

* Measurement of total & evaporative sweat loss corrected for evaporation and CO_2 excess (lungs).

FIGURE I

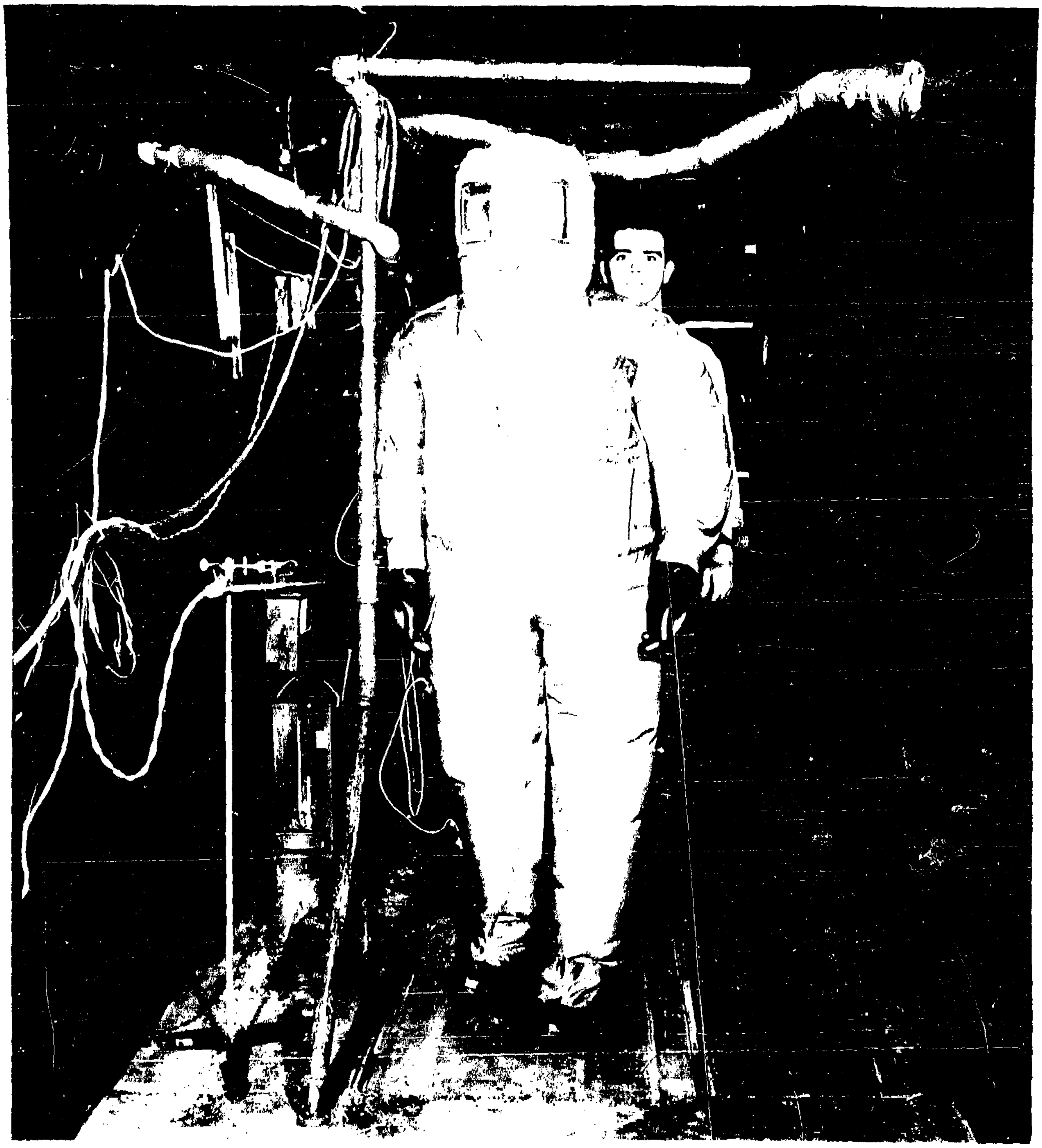
SKETCH OF AIR DISTRIBUTION SYSTEM
WITHIN VENTILATED SUIT



SPIDER MADE OF NONPERFORATED RUBBER TUBING OF 0.6" I.D.
(EXCEPT CENTRAL BELT WHICH IS 0.75" I.D.)

FIGURE I

Incl. #3

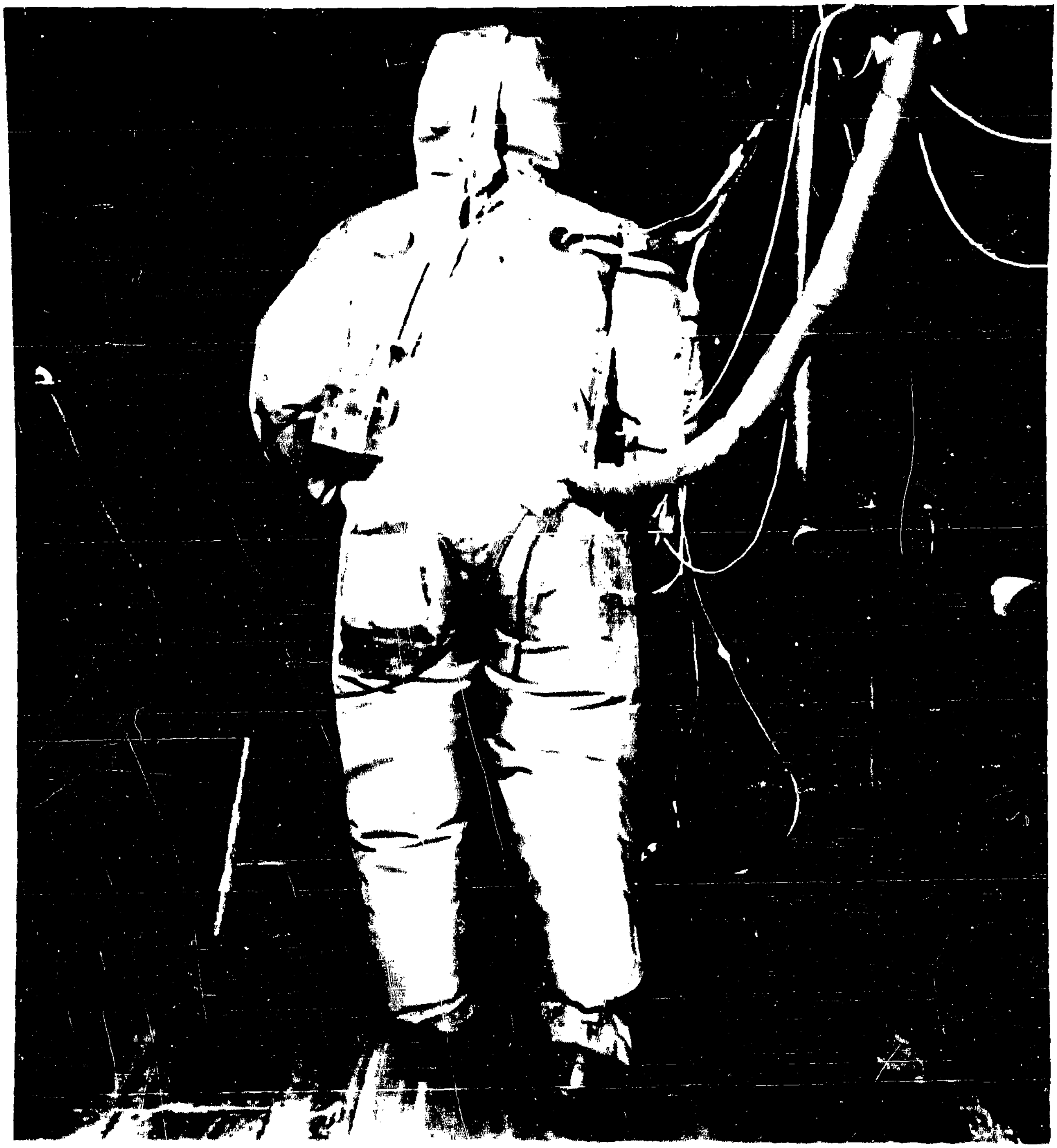


View of men on treadmill
showing some of test apparatus.

ARMORED MEDICAL RESEARCH LABORATORY

FORT KNOX, KY.

Project No. T-[illegible] [illegible]



Back View of Ventilated Suit
showing apparatus used in the test runs

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Project [illegible] Photograph #[illegible]

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